JOVIAN BROADBAND KILOMETRIC RADIATION: NEW OBSERVATIONS FROM ULYSSES

M. L. Kaiser* and M. D. Desch*

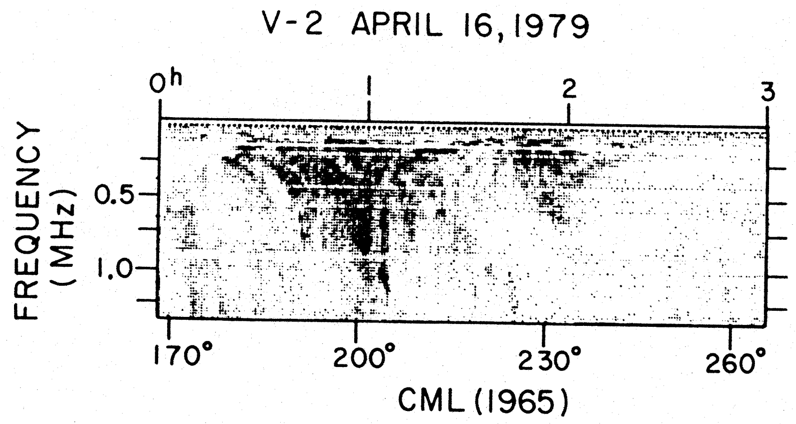
Abstract

The Ulysses unified radio and plasma wave experiment (URAP) covers the frequency range below 1 MHz with far greater sensitivity than the Voyager planetary radio astronomy instrument. This has allowed observations of Jovian radio emissions to commence early in the Ulysses flight to Jupiter. At frequencies below 150 kHz, the URAP instrument has especially good frequency coverage permitting, for the first time, the low frequency portion of Jupiter's broadband kilometric radiation (bKOM) to be studied synoptically. Initial observations showed that this low frequency bKOM varies dramatically with time, possibly the result of variations in the electron density in the Io plasma torus through which the bKOM must propagate, combined with variations in the solar wind input. Near the time of closest approach, as the spacecraft latitude increased, the low frequency limit of bKOM increased until bKOM was only observed above several hundreds of kHz. During the outbound trajectory, at high southern latitudes and in the dusk meridian, the 'traditional' bKOM pattern was replaced by a completely new pattern which could either be bKOM or some new radio component.

1 A Brief History of bKOM

Jupiter has long been the 'favorite' planet of low–frequency radio astronomers. (To support this statement, one need simply witness the number of papers on Jovian observations in these Graz Workshop series). It was with great excitement and expectation, therefore, that the two Voyager spacecraft, both carrying a Planetary Radio Astronomy (PRA) instrument, were launched toward Jupiter in 1977. The PRA instrument, described in detail by Warwick et al. [1977] covered the known and expected frequency range of Jovian non–thermal emissions from about 1 kHz to 40 MHz with a 198–channel receiver capable of measuring received power in both left–hand (LH) and right–hand (RH) circular polarization.

*Laboratory for Extraterrestrial Physics, Goddard Space Flight Center, Greenbelt, MD, USA 20771



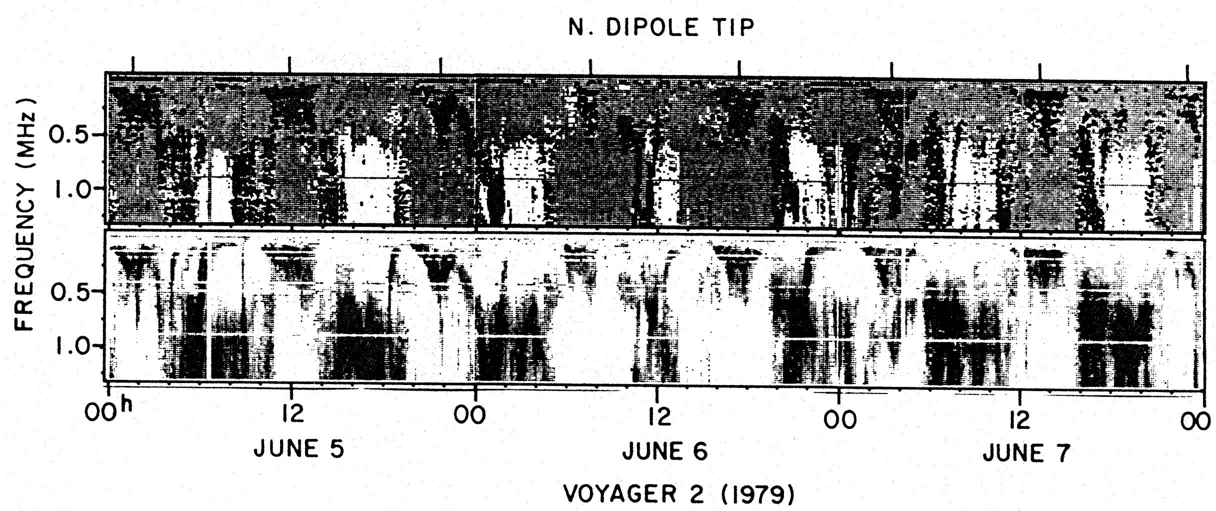


Figure 1: (top) A frequency–time spectrogram from the Voyager–2 PRA instrument showing a fairly typical bKOM event with its characteristic shape. (bottom) Several days of data again from the Voyager–2 PRA instrument (total power at bottom, sense of circular polarization at top with RH=black, LH=white) showing the repetitive nature of bKOM, centered near the time of North dipole tip passage past the spacecraft. Interspersed between the bKOM events at higher frequencies is Jovian hectometer (HOM) emission.

It was with this PRA receiver that two new Jovian radio components were discovered in the kilometer wavelength region [Warwick et al., 1979; Kaiser and Desch, 1980]. These two components differed from one another in several aspects, but the most obvious was the observed bandwidth from which their acronyms were derived, bKOM for broadband kilometric and nKOM for narrowband kilometric. The main subject of this paper, bKOM, was observed by PRA to extend from a few tens of kilohertz, where event durations were the longest, to at least 1 MHz, with peak flux near 100 kHz. In appearance, the bKOM resembled a triangle in frequency–time spectrograms marked by considerable temporal and spectral variability within a given episode. Finally, the bKOM was observed to recur at multiples of the Jovian rotation period, 9.92 hr, with emission tending to maximize with maximum magnetic dipole latitude. Figure 1 illustrates some of these properties. In the top panel, the overall triangular shape is obvious and some of the fine structure can be seen. In the bottom two panels, eight consecutive rotations of Jupiter are shown with PRA total power displayed in the bottom panel and the sense of circular polarization (RH=black, LH=white) in the middle. bKOM events are present at each passage of the Jovian north dipole tip past the observer, corresponding to Voyager reaching maximum magnetic dipole latitude. The polarization of these North pole events is RH.

2 The Ulysses Mission and the URAP instrument

The Ulysses Mission, launched on October 6, 1990, is a joint ESA–NASA undertaking whose main goal is to pass over the poles of the sun with a complement of field and particle instruments [see *Astron. & Astrophys. Suppl.*, vol. **92**, no. 1, 1992 and articles therein]. In order to reach such high heliographic latitudes, it is necessary to use the gravitation of Jupiter. Even though the primary Ulysses science is solar, the rather unusual trajectory during the Jupiter gravity–assist flyby permits unique observations to be made which will not be duplicated in the foreseeable future.

Figure 2 shows the trajectory of Ulysses at Jupiter in the Jovian equator plane (top) and in a folded meridian plane (bottom). The trajectory carries Ulysses to very high northern latitudes just before closest approach (C.A. Feb. 8, 1992 at 12:00), followed by a near north–south plunge through the outer reaches of the Io plasma torus to an outbound trajectory at high southern latitudes near the dusk meridian.

Among the various field and particle instruments, Ulysses carries the Unified Radio and Plasma wave (URAP) experiment. This instrument consists of a set of plasma wave and radio receivers covering, with great sensitivity, the range from DC to 1 MHz [Stone et al., 1992]. A summary of the URAP instrument is given in Table 1. The particular portion of the URAP instrument of interest here is the radio astronomy receiver (RAR) which operates in two bands, one covering the range from about 1 to 50 kHz in 64 linearly spaced channels of 750 Hz bandwidth, the other covering the range from about 50 kHz to 1 MHz in 12 logarithmically space channels. A comparison of the frequency coverage of URAP and PRA is shown in Figure 3. One can see that URAP provides particularly good coverage in the low frequency portion of bKOM.

In addition to the good frequency coverage, URAP is effectively 100 to 2000 times as sensitive as the PRA instrument due primarily to the much longer wire antennas on Ulysses as compared to Voyager (72–m tip–to–tip versus 10–m) and to the electrically very quiet Ulysses spacecraft. This has allowed URAP bKOM observations to commence at a much earlier time during the flight to Jupiter compared to PRA.

Additionally, the Ulysses spacecraft spins at about 5 rpm, allowing direction of arrival to be determined from spin modulation. A second antenna on the spacecraft spin axis can be electrically combined with the long dipole to produce the equivalent of a tilted dipole allowing two–dimensional direction of arrival information to be determined. Also, insertion of phase delay lines allows URAP to measure all four Stokes parameters, thereby completely determining the wave polarization state.

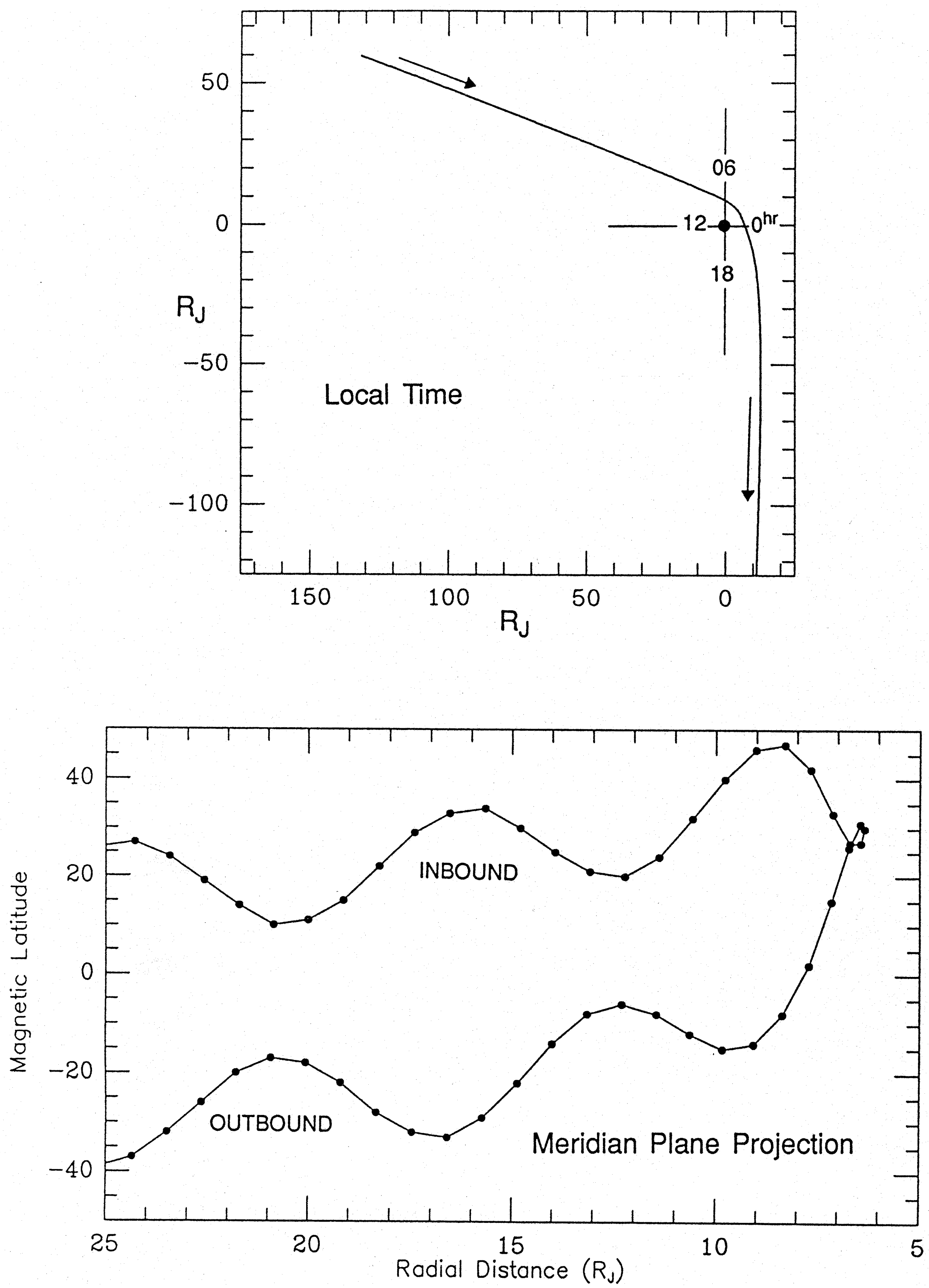


Figure 2: The Ulysses trajectory past Jupiter projected onto the Jovigraphic equator plane (top) and magnetic meridian plane (bottom).

Table 1. Characteristics of the Unified Radio and Plasma Wave Experiment

Instruments and Bands		Measurements	Frequency Range	Maximum Channels	Channel Bandwidth	Data or Spectrum Time Resolution	Dynamic Range	Sensitivity (rms)
Radio Astronomy Receiver (RAR)	Hi	E_X and E_X+E_Z (δ=0) plus E_X+E_Z (δ=90) at 1024 bps	52-940 kHz	12	3 kHz	24 samples/spin for 3 frequencies at 1024 bps	70 dB (power) + 20 dB Jupiter attenuator	10 nV/Hz$^{1/2}$ @ 100 kHz
	Lo	- OR - E_X and E_Z only	1.25-48.5 kHz	64	750 Hz	36 samples/spin for 1 frequency at 1024 bps		30 nV/Hz$^{1/2}$ @ 10 kHz
Plasma Frequency Receiver (PFR)		Peak E_X, Ave. E_X & Ave. E_Z	0.57-36 kHz	32 log-spaced by 14%	14% of center frequency	16 frames* used to transmit 1 set of spectra	2 μv to 3 volts per channel	100 nV/Hz$^{1/2}$ @ 10 kHz
Waveform Analyzer (WFA) (FFT-DPU)	Hi	Ave., Peak & relative phase of E_X, B_Y & (E_Z or B_Z)	9-448 Hz	12 log-spaced by 25%	30% of center frequency	4 sets of spectra/ 2 formats*		E:2 μV/Hz$^{1/2}$ @ 100 Hz
	Lo	Ave., Peak &relative phase of E_X & (B_Y or B_Z)	0.08-5.3 Hz	12 log-spaced by 25%	30% of center frequency	1 set of spectra/ 16 frames*		B:30 $\mu\gamma$/Hz$^{1/2}$ @ 100 Hz
Fast Envelope Sampler (FES)	Hi	E_X or E_Z	0.6-60 kHz	1of 3	E: Extends from f_{min} to 10 times f_{min}	1 sample/1.2 ms (fastest rate) 1024 samples/ event	64 dB plus 32 dB attenuator	E_X: E_Z: B:
	Lo	E_X, E_Z or (B_Y or B_Z)	E:0.1-20 kHz B:10-600 Hz	1of 4 1of 1				

"DC"	Outputs of X and Z PFR preamps for monitoring DC potential & low freq. fluctuations. Fixed angle & scan measurements.
Sounder	30 volt pulse applied to X antenna for 1.33 ms. Low frequency RAR steps through 64 frequencies in 128 sec. 12 point spectrum for each frequency step yields 768 linearly spaced frequencies between 1.25 & 48.5 kHz.
Antennas	E_X: two 35 m monopoles, 72.5 m tip-to-tip, 5x0.04 mm cross section; E_z: 8 m monopole, 25 mm cross-section; B: 2-axis search coils.
Notes	At 1024 bps, 1 frame of data=1 sec.; 32 frames = 1 format*. RAR: Can measure full polarization (4 Stokes parameters) plus source direction & angular size. Commandable frequency lists, including linear sweep (Lo band) & freeze modes. Spin period ~12 sec. WFA: Average spectra for each quadrant in Hi band are grouped with opposing octant. FES: Largest 1024 point event telemetered each 49 formats. Sounder: Uses FFT-DPU when active; displaces WFA and some PFR telemetry.

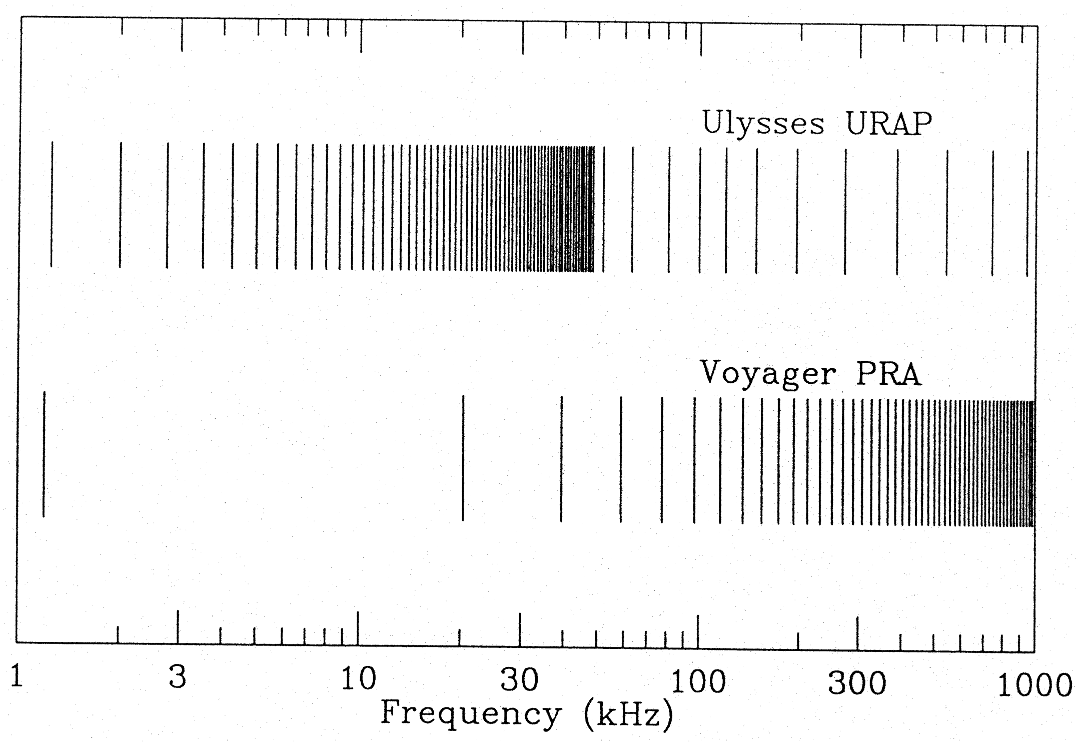


Figure 3: Comparative channel spacing in the radio astronomy range showing URAP's strong emphasis on the low frequency region.

3 URAP observations of bKOM

Figure 4 shows one of the early URAP observations where bKOM is clearly delineated. At the time of the observation, the spacecraft was in the Jovigraphic equatorial plane (although still some 4 A.U. from the planet). bKOM is clearly seen associated with both the North pole and South pole of Jupiter.

From these relatively low latitudes near the Jovigraphic equator, bKOM was observed with approximately equal occurrence with both Jovian poles. Figure 5 shows a comparison with some of the Voyager PRA data. The bKOM associated with the longitudes of the Jovian South pole are virtually non existent as viewed by Voyager 2 at +7 degrees latitude. For

Figure 4: (Color plot, next page) Dynamic spectra taken by URAP more than one year before closest approach. Note that the URAP convention is for high frequencies to be displayed at the top and low at the bottom, opposite to the PRA convention as shown in Figure 1. The time scale of the plot is 9.92 hours corresponding to one Jovian rotation. The start time of the rotation is shown at the top. The URAP receiver is shown in two bands with different scales for each (high band logarithmic, low band linear). Visible in this figure is the solar wind plasma frequency near 10 kHz, a band of unresolved solar type III bursts between 200 and 500 kHz with one particularly intense type III near 270 degrees and bKOM. The bKOM extends over both bands of the receiver and can be seen in the system III longitude range of 0 to 60° (South pole at about 20 degrees), and 140 to 220° (North pole at 200 degrees).

Comparison of bKOM Occurrence statistics PRA vrs URAP

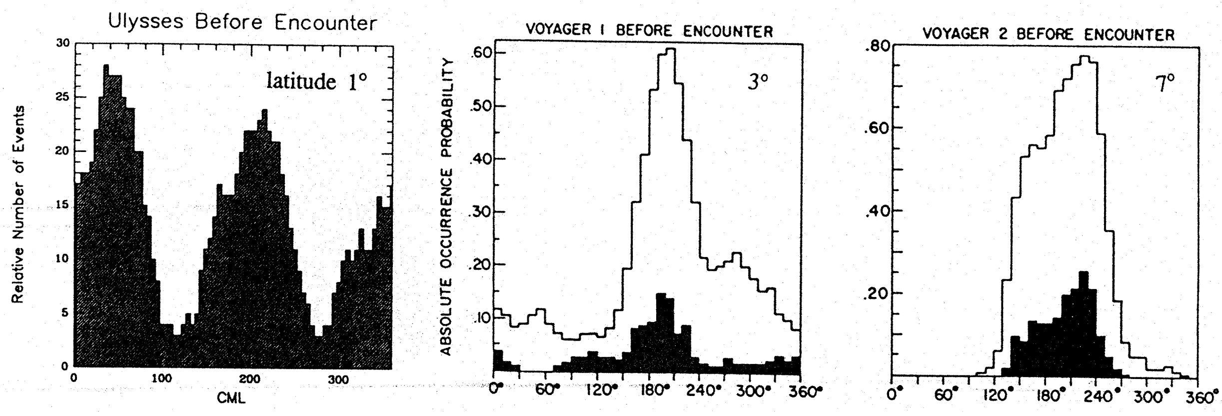


Figure 5: Comparison of the overall occurrence of bKOM as a function of system III longitude and observer's latitude. For Voyager 2 at relatively high latitude, the North pole bKOM is the only component observed. For URAP near the Jovigraphic equator bKOM occurs at approximately equal rates for both North and South polar longitudes. Voyager 1 at intermediate latitudes is still dominated by the North, but some South emission is visible. The dark insets for the Voyager panels represent more intense bKOM events.

Voyager 1 at +3 degrees, some South pole bKOM is evident. For Ulysses near the equator, the South pole emission is comparable to or may even exceed the emission associated with the North pole.

Figure 6 shows an interval from near closest approach where the latitude of Ulysses is about +10 degrees. The emission that was associated with the South polar region is essentially gone, and the North pole emission is seen only at relatively high frequencies (>200 kHz). The dominant signal during this high latitude episode is not bKOM, but nKOM.

The temporal structure of bKOM at low frequencies became quite evident with the URAP observations. Figure 7 shows two examples of the nature of this temporal behavior. At frequencies below about 50 kHz, bKOM tends to form 'striations' in the dynamic spectra, often splitting into two or more vertical branches. The top panel shows a rotation where only a few of these striations appear, whereas the bottom panel shows a much more complicated structure. At times, bKOM seems to consist of extremely fine striations.

During the outbound portion of the Ulysses trajectory, the 'view' of Jupiter was quite different from that of any previous spacecraft. Not only was Ulysses at very southerly latitudes (< -35 degrees), but it was near the dusk terminator. As a result, the observations of bKOM are quite different from those obtained inbound. Figure 8 shows a typical Jovian rotation outbound. The familiar bKOM pattern of emission concentrated near the longitudes of the North and/or South pole is no longer apparent. In addition, the near–vertical striations of Figure 7 are missing, being replaced with long, upward drifting features. Therefore, even though the frequency range of the features in Figure 8 is nearly the same as bKOM, we cannot be certain at this time (Feb. 1992) that this emission is the same as that observed previously. This may possibly be a new radio component that has not been observed before.

4 The future of bKOM studies

The detailed analysis of the URAP bKOM observations has barely begun. Indeed, as of this writing just after the closest approach, the direction of arrival and polarization data have not been studied at all. These data are crucial in order to resolve the problem of the source location(s) of bKOM and the base mode of the emission. Also, the rather extreme variations of the appearance of bKOM as a function of latitude and/or local time will yield important information in the immediate future.

Somewhat more distant in time will be the synoptic observations of bKOM from the Galileo spacecraft, due to begin orbiting Jupiter in 1996. However, the Galileo spacecraft is currently crippled by a non operating high gain telemetry antenna, so the data rate possible from Jupiter might be severely compromised unless the antenna can be restored.

Beyond Galileo, the only currently funded mission capable of adding to the bKOM story is the Cassini mission to Saturn. This mission is scheduled to fly past Jupiter in the late 1990s or early in the next century.

Figure 6: (color plot, next page) Dynamic spectrum from URAP only a few days before closest approach to Jupiter. Format is the same as Figure 4. South pole bKOM has disappeared at this latitude (10 degrees), and North pole bKOM is restricted to frequencies above about 200 kHz at longitudes from 180 to 220 degrees. HOM emission can be seen at the highest frequencies between 300 and 60 degrees, and trapped continuum dominates at the very lowest frequencies. The long upward drifting series of tones in the 100 to 200 kHz range and between 60 and 360 degrees longitude is nKOM.

Figure 7: (color plot, following page) Dynamic spectra from URAP in the same format as Figure 4 showing variations in the vertical striations observed in the low frequency bKOM emission. The intense band of emission below about 15 kHz is escaping continuum.

Figure 8: (color plot, following page) Dynamic spectra from URAP a few days past closest approach where Ulysses latitude is < -35 degrees. The normal South–North pattern of bKOM observed during the inbound portion of the Ulysses trajectory and during both legs of the Voyager trajectories is now replaced by this rather chaotic pattern which shows emission at nearly all longitudes with some diminution near the North polar longitudes. The mottled appearance of the emission at frequencies below 50 kHz is caused by strong spin modulation due to the orientation of Jupiter in the URAP antenna spin plane during the outbound trajectory. Also evident in the figure at very low frequencies is the continuum emission.

References

Kaiser, M. L. and M. D. Desch, Narrow–band Jovian kilometric radiation: A new radio component, *J. Geophys. Res.*, **82**, 3273, 1980.

Stone, R. G., J. L. Bougeret, J. Caldwell, P. Canu, Y. de Conchy, et al., The Ulysses unified radio and plasma wave investigation, *Astron. & Astrophys. Suppl.*, **92**, in press, 1992.

Warwick, J. W., J. B. Pearce, R. G. Peltzer, and A. C. Riddle, Planetary radio astronomy experiment for the Voyager mission, *Space Sci. Rev.*, **21**, 309, 1977.

Warwick, J. W., J. B. Pearce, A. C. Riddle, J. K. Alexander, M. D. Desch et al., Voyager 1 planetary radio astronomy observations near Jupiter, *Science*, **204**, 995, 1979.